Advancement of Entry System Modeling to Support Exploration of Giant Planets

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This paper describes NASA's efforts to advance entry system modeling and simulation capabilities to support future exploration of Giant planets. The Giant planets are key destinations of interest to the planetary science community for their potential to provide insight into the formation and evolution of our Solar System, as well as extrasolar planetary systems. To date, the Galileo atmospheric probe is the only purpose-built entry probe to a Giant planet. Post-flight analysis of Galileo's performance showed that there was significant recession of the thermal protection system (TPS), well beyond what was anticipated on the flank, and this was due in part to insufficiently accurate capability for estimating the flight environment and TPS response. While Galileo ultimately survived its flight, the example serves to highlight the great challenge of designing successful missions for environments that are poorly understood or where models have not yet been validated. An important means to reduce mission risks is the incorporation of physics-based modeling with well-quantified uncertainties. The emphasis on physics-based modeling – in contrast to empirically-driven models – is motivated by the fact that it is impossible to completely replicate entry environments through ground tests and, therefore, extrapolation to the flight environment is required. Basing analysis in fundamental physics removes the bias of ground test limitations, though one must then be careful to properly characterize model inputs, simplifying assumptions, and the limits wherein the model is valid.

NASA's Entry Systems Modeling (ESM) Project is tasked with investigating such considerations for planetary science missions across the Solar System, and in recent years has begun to do so for Giant planets. The most distinctive features of the Giant planets, from an entry system perspective, are the atmospheres composed primarily of hydrogen and helium. The entry velocities of proposed missions are generally very large and can therefore be expected to result in significant convective and radiative heating generated by the vehicle's shock layer. Yet thermochemical behavior of the hydrogen-helium system is not well understood under such conditions. The ESM project is leading efforts to develop accurate thermochemical databases based on state-of-the-art measurements in the Electric Arc Shock Tube and detailed computational chemistry. The large heat fluxes anticipated by missions has driven interest in new TPS materials, in particular woven materials, which may be enabling but have never been flown before. Consequently, multiscale models are in development to describe properties and performance of the materials from micro- to system-scale. The goal is to not only provide accurate thermal response but also to inform thermostructural reliability predictions for extreme entries. Additionally, new computational models have been developed to evaluate performance of non-destructive evaluation techniques which are vital to establishing acceptance of systems to be free of manufacturing faults like material cracking, voids, and debonding. Finally, in the area of guidance and control, aerocapture has been shown conceptually to provide a number of mission benefits, including reducing transit time and increasing payload fraction. The ESM project is building a launch-to-landing trajectory simulation capability to enable detailed studies of aerocapture maneuvers in the context of

Giant planets missions. The final presentation and paper will describe each of these topics in detail, including discussion of specific gaps and the technical approach to solving them. In addition, the final paper will briefly discuss ongoing coordination between ESM project work and an ESA-funded technology development activity comprised of validation testing in the Oxford T6, IRS PWK and IST ESTHER tunnels, as well as state-to-state modeling of the shock layer to better represent non-Boltzmann energy distributions leading to non-equilibrium radiation.